FARADAY REPORT – MARCH 2020
ANNUAL GIGAFACTORY STUDY

THE FARADAY INSTITUTION

UK electric vehicle and battery production potential to 2040

Front cover photo courtesy of Jaguar Land Rover

Summary

Governments and legislatures around the world are increasingly committed to the electrification of road transport as a means to reach Net Zero and decarbonisation commitments. Car manufacturers are responding. They are investing now in the production of electric vehicles (EVs), which will result in a corresponding decrease in internal combustion engine (ICE) vehicle production. Given the lead-times involved, and the possibility that new sales of petrol and diesel vehicles will end in 2035, it will not be long before they stop investing in new production lines for vehicles equipped with internal combustion engines.

The question is not whether this transition will occur. Rather, the question is whether some of the new generations of EVs[1] will be produced in the UK, or whether the UK will gradually cease to be a manufacturer of vehicles and become an importer.

The answer to this question will depend in part, of course, on whether the UK remains a sensible place for manufacturers to locate the production of vehicles, the vast majority of which are currently destined for export. This will heavily depend, in turn, on the final outcome of the post-Brexit trade negotiations. But, alongside the issue of the UK's trading relationship with the EU, the most important determinant of the future health of the automotive industry in this country will be whether batteries are manufactured in the UK.

Strong synergies[2] can be achieved when vehicle producers and battery manufacturers are situated in close proximity to one another. Given the fierce competition within global automotive production networks, these synergies will heavily affect the location of vehicle production. As a result, if the new gigafactories required to assemble the batteries used in EVs are solely built outside of the UK, there is a high risk that international car makers will also only invest in production of future EV models in plants outside the UK.

For this reason, the switch to the production of EVs puts jobs in the UK automotive industry at risk. In a worst-case outcome, with no large scale UK battery production, domestic vehicle producers would gradually wind down their production of internal combustion engine vehicles, progressively eliminating the jobs of the 170,000 people directly employed in the UK automotive sector.[3] The speed of this change is difficult to predict, since it depends on a number of variables that we have modelled. But, under any plausible set of modelling assumptions, the scale of the effect would be considerable. **In the absence of any gigafactories producing batteries and associated EV manufacturing, we forecast that direct automotive employment would be 105,000 lower in 2040 than it would otherwise be.**

At the opposite end of the spectrum of possibilities, the UK – in partnership with investors from Asia and elsewhere – could become a leader in the production of both batteries and EVs. In this scenario, the UK would build upon its strong existing automotive industry and greatly expand its global market share by establishing itself as a European centre for battery and EV production. This could lead to a substantial increase in UK vehicle production relative to today. However, this outcome will be challenging to achieve and will depend both on successes within the UK that will be difficult for UK governments to bring about and failings elsewhere in Europe.

We have accordingly focussed not on this upside scenario, but on the actions necessary to avoid the downside case of progressive decline in our automotive industry. Our starting point is the question:

How can the UK Government and participants in the UK automotive industry ensure that the UK has sufficient battery assembly plants to sustain a level of electric vehicle production in the UK at least equal to the UK's current share of the internal combustion engine vehicle market?

For the purpose of answering this question, we have assumed in our central scenario that the UK automotive sector otherwise remains stable (e.g. in terms of aggregate UK vehicle demand and UK-EU trading relationships), and that demand for EVs in the UK keeps pace with the trends in global demand for such vehicles.

[1] In this report, EV is taken to include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hybrid electric vehicles (HEVs).
[2] These include greater flexibility for just-in-time production, greater reliability of supply chains against political and climate shocks, and the formation of a knowledge ecosystem around battery systems.
[3] SMMT (2015-19). Motor Industry Facts 2015-19. Because of the fluctuation in the automotive industry in recent years, the 2020 base year for UK employment and UK vehicle production is calculated from a five-year average over the 2015-2019 period.

UK battery production potential to 2040

The growth of the UK EV production and battery production industry in our central scenario (or base case) will depend upon a range of factors, including:

1) the volume of global vehicle sales,

2) global emissions regulations,

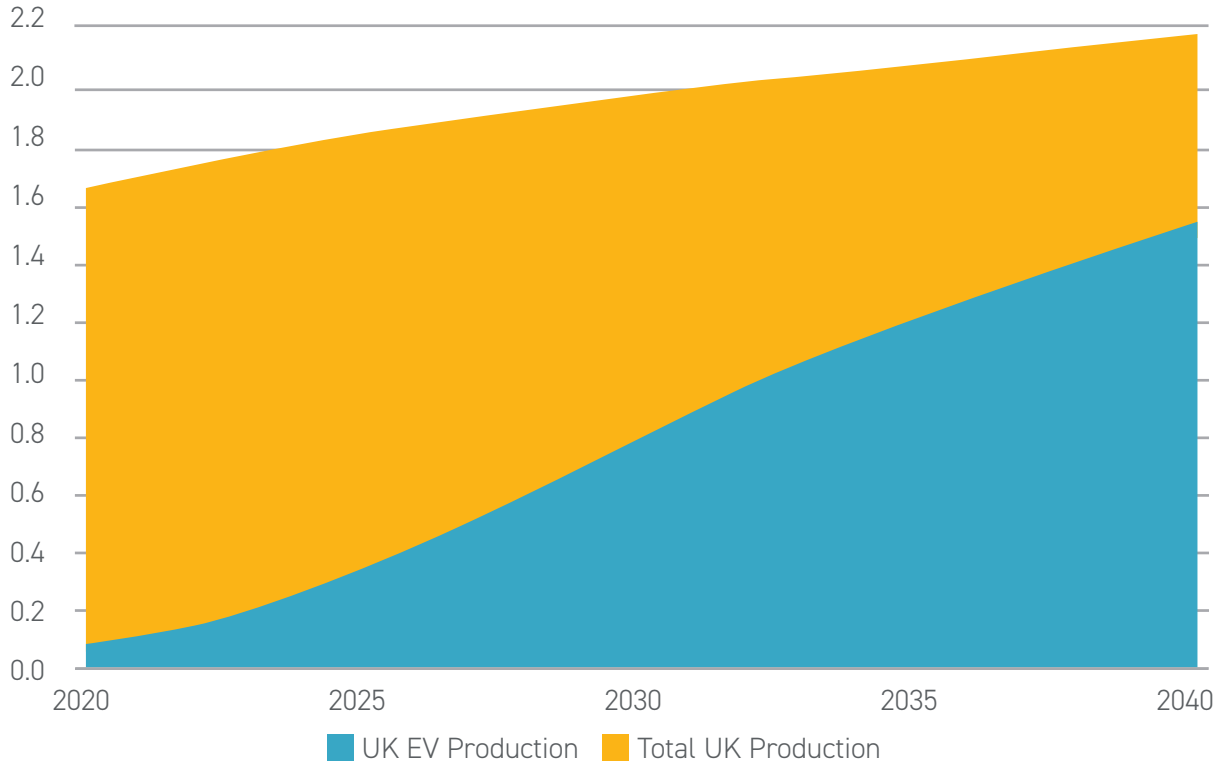
3) the rate of decline in EV battery costs,

4) growth in EV battery range, and

5) the import-export environment.

The export market environment is clearly the key factor given that the UK exported 80% of its 1.6 million domestically produced vehicles,[4] of which over half were exported to Europe. In these export markets, we forecast aggregate vehicle sales to grow by an average of 1.4% per year over the 2020 to 2040 period, driven mainly by demand outside of Europe and the United States, most notably from China. Applying different assumptions about emissions regulations, the decline in EV battery costs and the increase in EV battery range, this generates our central scenario projection that the UK will be producing nearly 1.6 million EVs per year by 2040.

Vehicles produced in UK, millions/year



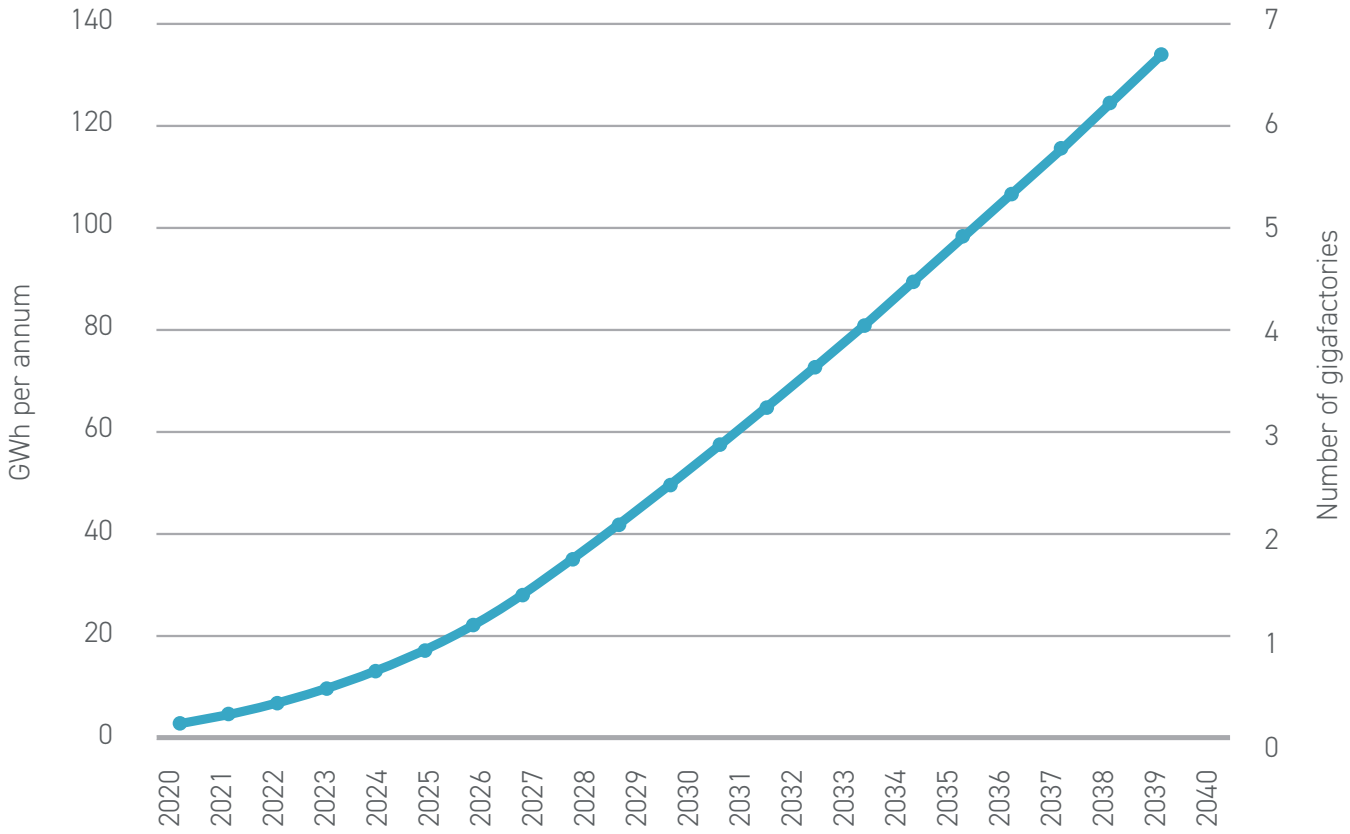
Note: Our forecast projects UK automakers will produce 1.6 million EVs per year by 2040. This is based on UK production growth of 2% p.a. over the 2020-25 period, 1.5% over 2025-30 and 1% thereafter.

With the 'Road to Zero' strategy, launched in summer 2018, the UK Government has set ambitious targets for EV sales in the UK. The strategy sets out the intention that at least 50%, and possibly as many as 70%, of new vehicle sales in 2030 will be of ultra-low emissions models. The government has also recently announced a consultation on bringing forward the end of the sale of new petrol and diesel cars and vans from 2040 to 2035.[5]

[4] 2015-2019 five-year average from SMMT Vehicle and Manufacturing Data (2015-2019). Vehicles numbers comprise 'Passenger Cars' and 'Commercial Vehicles'.
[5] Government press release (4th February 2020). PM launches UN Climate Summit in the UK.

It is worth noting that, as the battery makes up 40% of an EV's value, meeting the UK's EV battery demand under this scenario would increase annual UK imports by around £9 billion per year by 2040 if the batteries were (implausibly) sourced 100% from overseas suppliers. But, given that EV production at this level will almost certainly depend upon the establishment of a **secure domestic EV battery supply**, the more interesting point is that the accompanying UK battery production facilities represent a considerable industrial opportunity for the UK.

Projected demand for UK-produced batteries



Note: An average mature gigafactory is estimated to have a capacity of around 20 GWh per annum.

Under our central scenario, the Faraday Institution battery demand forecasting model projects that UK EV battery manufacturing capacity in 2040 will be around 140 GWh per year[6] (i.e. around 12% of the projected 1,200 GWh per year European battery production capacity in 2040[7]).

This implies a very considerable growth in UK battery manufacture with the establishment over the next twenty years of about 7 battery production plants ("gigafactories") in the UK with each producing on average 20 GWh of battery capacity each year.[8]

Economic, employment and skills impacts

The global transition from producing internal combustion engine vehicles to producing EVs will have a considerable impact on the UK labour market. Job creation will outpace job losses in the UK only if the UK secures both EV and battery manufacturing.

[6] This is our central scenario. Using optimistic and pessimistic assumptions we forecast demand for UK-produced batteries ranges from a low of 60 GWh per annum by 2040 to a high of 220 GWh per annum.
[7] McKinsey (June 2019). Recharging economies: The EV-battery manufacturing outlook for Europe.
[8] Recent developments since our previous report suggest that the 'average' capacity of a mature gigafactory has increased from 15 GWh to 20 GWh per annum. Gigafactories will typically start off with a capacity of, say, 8-10 GWh p.a. and then increase in clear steps to 15 GWh p.a. and to 20-30 GWh p.a. as they mature.

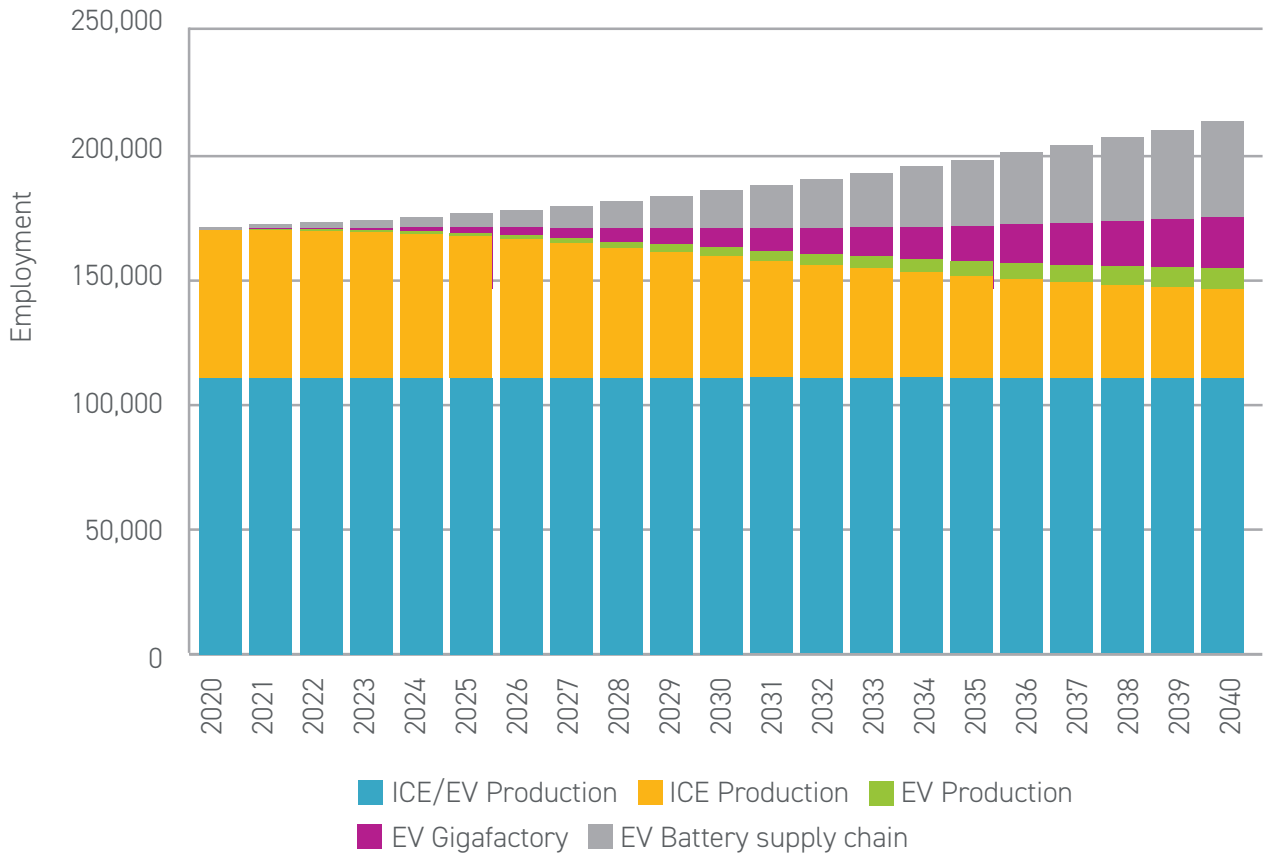
Under our central scenario, we project that battery pack, battery cell and electrode manufacturing will all be located in the UK. In this scenario, the overall industry workforce of the automotive and EV battery ecosystem would grow by 29% from 170,000 to 220,000 employees by 2040 with:

- 78,000 new jobs created in the new UK battery gigafactories and in their battery material supply chains;
- 32,000 jobs remaining in ICE vehicle production; and
- 110,000 jobs remaining in powertrain manufacturing serving both ICE and EV production.

Of the 78,000 new jobs by 2040, 24,500 jobs in battery manufacturing, 43,500 jobs in the battery supply chain and around 10,000 would be created in EV manufacturing.

These estimates are based on an assumption that an average of 180 battery manufacturing jobs are supported per GWh per annum (i.e. 140 jobs for battery 'cell' manufacturing[9] and an additional 40 jobs per GWh per annum for battery 'module and pack' assembly[10]) and that 1 direct job supports a further 1.8 battery supply chain or indirect jobs. There will of course be wider indirect supply chain impacts with jobs supported outside the automotive and battery industry (in logistics, mechanical engineering, construction, finance, sales & marketing etc.), which is substantial but not included in these figures.[11]

ICE and EV employment 2020 to 2040



Note: Under our base case scenario, we project that powertrain indifferent jobs remain unchanged over the period to 2040 at 110,000, based on the assumption that the 1.4% per annum growth in EV and ICE vehicles produced in the UK is offset by the same per annum increase in labour productivity.

[9] Joint Research Centre, European Commission (2017). EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions.
[10] Estimated that 30% more jobs are supported in module and pack assembly, attributing employment impacts in proportion to the percentage split in the price of producing cells and packs (see BNEF 2018, A Behind the Scenes Take on Lithium-ion Battery Prices).
[11] The Northvolt gigafactory is estimated to support 20,000 indirect jobs in addition to the 2,500-3,000 direct jobs, as reported in the study 'EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications' by Joint Research Centre, European Commission (2017).

Different skills and qualification levels are required by the gigafactory workforce depending on the complexity of the role. 'Production Operators' (or associates) are predominantly on-the-job trained against quality, cost and delivery criteria. These operators mostly perform codified manual tasks which could not be automated due to technical or cost constraints. 'Equipment Technicians' work very closely with the production operators ensuring that the automated part of the manufacturing process is working efficiently.

Together these two categories account for around 75% of the workforce in a gigafactory and would typically require level 2 or level 3 qualifications in a course such as Advanced Manufacturing Engineering. Candidates for these roles could be found in other high-volume manufacturing sectors such as the processed food industry or pharmaceutical production. Additional training on the risks of working with chemicals and hazardous materials in a production environment would be required to upskill these workers.

The remaining 25% of positions are highly skilled jobs requiring higher-level qualifications. Some of the engineering positions such as systems engineer, database development engineer and thermal management engineer would require a very high level of skills and qualifications (e.g. PhDs). Higher skills would not only be required for the technical nature of cell manufacturing but also to develop a competitive edge by keeping abreast of factory advances such as the industrial Internet of Things, data-driven production, optimisation, automation, materials analysis, continuous improvement and simulation.

Job types and skills required for a typical gigafactory

Job types	Typical employment activities undertaken	% split & qualification level
Production Operators	Material handling, machine loading, machine unloading, pack assembly, logistics, module/pack assembly, inspection	60% Level 1-3
Equipment Technicians	Machine service, machine maintenance, optimising machine performance, quality control, reviewing cost & delivery	15% Level 3-5
Engineers & Senior Staff	Facility engineers, process/production engineers, IT and data management, achievement of KPIs, legislation checks	10% Level 6 and up
Quality Technicians	In-process controls, confirmation of specifications (parts and supply), performance evaluation, assessment of defects	5% Level 4
Quality Engineers	In-process controls, confirmation of part /supply specification, performance evaluation, defect analysis	5% Level 6
Management & HQ functions	HR, finance, purchasing, IT and data management	5% Level 6 and up

The shift toward EVs will also necessitate the retraining of auxiliary personnel, including vehicle technicians, mechanics and electricians, as well as staff at service stations. These changes to the labour market will depend on the UK's uptake of EVs rather than on the UK's production of EVs, a trend that falls outside the scope of this study.[12]

As well as the direct gigafactory employment, battery production has the potential to create new jobs in the supply chain. In particular, large scale battery cell manufacturing would support highly skilled jobs in the UK chemical sector and represents a £4.8 billion opportunity by 2030.[13]

[12] We also analyse the labour market effects of the less plausible possibility that the UK will manage to replace ICE vehicle production with EV production, despite failing to achieve an increase in battery manufacturing capacity. We project that the lower labour-hours necessary to assemble an EV drive train compared to an ICE vehicle drive train – partly owing to increased automation – will result in a reduction of an approximately one-quarter in the vehicle assembly workforce in this case.
[13] Automotive Batteries, April 2019, by the Advanced Propulsion Centre UK and Innovate UK, Supported by KTN & WMG, University of Warwick, Authored by E4tech.

Competitive landscape and required investments

Assuming successful resolution of the UK-EU trading relationships, the UK currently offers a competitive business environment for attracting prospective battery cell producers when compared with other countries in Europe. The UK is the 4th largest vehicle manufacturer in Europe, with nearly a decade of experience of EV battery production, following the establishment of the first and largest battery production facility in Europe (the AESC battery plant in Sunderland) in 2010.

The UK Government has also provided support to the industry through the Faraday Battery Challenge investment of £274 million over the 2017-2021 period. This challenge aims to support a world class scientific, technology development and manufacturing scale-up capability for batteries in the UK. This UK strategy is perhaps the only one around the world which joins up research, technology development and manufacturing. The aim of the challenge is to develop cost-effective, high-performance, durable, safe and recyclable batteries to capture a growing market. A key part of the challenge is a £129 million UK Battery Industrialisation Centre[14] which will enable companies of all sizes to develop manufacturing capabilities for battery technologies to get them to market quickly.

But other European countries and governments are also working hard to secure and grow a new battery industry and challenge the UK technology leadership position. Germany, Sweden, Poland and Hungary have emerged as key leaders and have done so by creating favourable business conditions to attract battery manufacturers. Germany and France, for example, have announced €1 billion and €700 million respectively of financial support towards EV battery production.[15,16] In Poland and Hungary, special economic zones have been set up that offer tax relief to EV battery producers. The European Commission has also recently approved €3.2 billion of public funding, from Belgium, Finland, France, Germany, Italy, Poland and Sweden, for pan-European research across the battery value chain.[17]

Plans for new battery manufacturing capacity in continental Europe currently have increased substantially over the past year or so. Some of the significant announcements by battery manufacturers are summarised in Box 1 on the next page.

To obtain the full benefits of EVs towards net zero goals, EVs and their batteries need to be manufactured using electricity with a high proportion of renewables in the energy mix. According to Bernstein Research,[18] the impact on CO_2 emissions from battery manufacturing and its supply chain (what is now called a "mines to wheels" analysis) has become an increasingly important calculation. While most of the emissions from the full 10-12 year lifetime of a car come from the energy mix of the generated electricity in the country where the vehicle is charged, a full analysis calls for measuring the energy mix of the electricity used to manufacture the battery.

Northvolt have announced their intention of only using renewable sources of power at their two gigafactories, while the energy mix providing electricity to gigafactories in Poland and Germany and in Asia (China, Japan, and South Korea) use significant proportions of coal, oil and natural gas. Battery manufacturers will need to take such considerations into account as they make investment decisions regarding the siting of gigafactories. Norway, Sweden and the UK, with their high and increasing use of renewables, will become increasingly attractive in this regard.

[14] UK Battery Industrialisation Centre News. More than £60m of equipment delivered by UKBIC. The total funding is split by £111m of public funding and a £18m loan from the West Midlands Combined Authority.
[5] Reuters (13 November 2018. Germany has set aside €1 billion to support battery cell production.
[16] Electrive (14 February 2019). France to invest €700M in battery cell production.
[17] European Commission (9 December 2019). State aid: Commission approves €3.2 billion public support by seven Member States for a pan-European research and innovation project.
[18] Climate Change and Decarbonisation: Mobility - How Green is the Electric Revolution, and Will Fuel Cells Play a Role?, 19 September 2019.

Box 1: Key gigafactories plans announced in Europe

CATL, Erfurt (Germany). CATL announced an expansion in February 2019 on its original plans with annual 60 GWh production capacity now expected from 2026. CATL have guaranteed to supply Honda with 56 GWh of cells to 2027 through a MOU partnership.

LG Chem, Wroclaw (Poland). Capacity of 70 GWh per annum by 2022 with total investment estimated to be €2.8 billion, with the EBRD providing a €250 million loan.

Northvolt Ett, Skellefteå (Sweden). An initial line of 16 GWh per annum capacity in 2021, rising to 32 GWh by 2024 and the potential to expand to 40 GWh.

Northvolt Zwei, Salzgitter (Germany). A joint venture between Northvolt and Volkswagen agreed in September 2019 with plans to open the Salzgitter cell production facility with phase 1 capacity of 16 GWh per annum and plans to expand to 24 GWh per annum at a later date.

Samsung, Göd (Hungary). A plant with 15 GWh p.a. capacity expected by 2020.

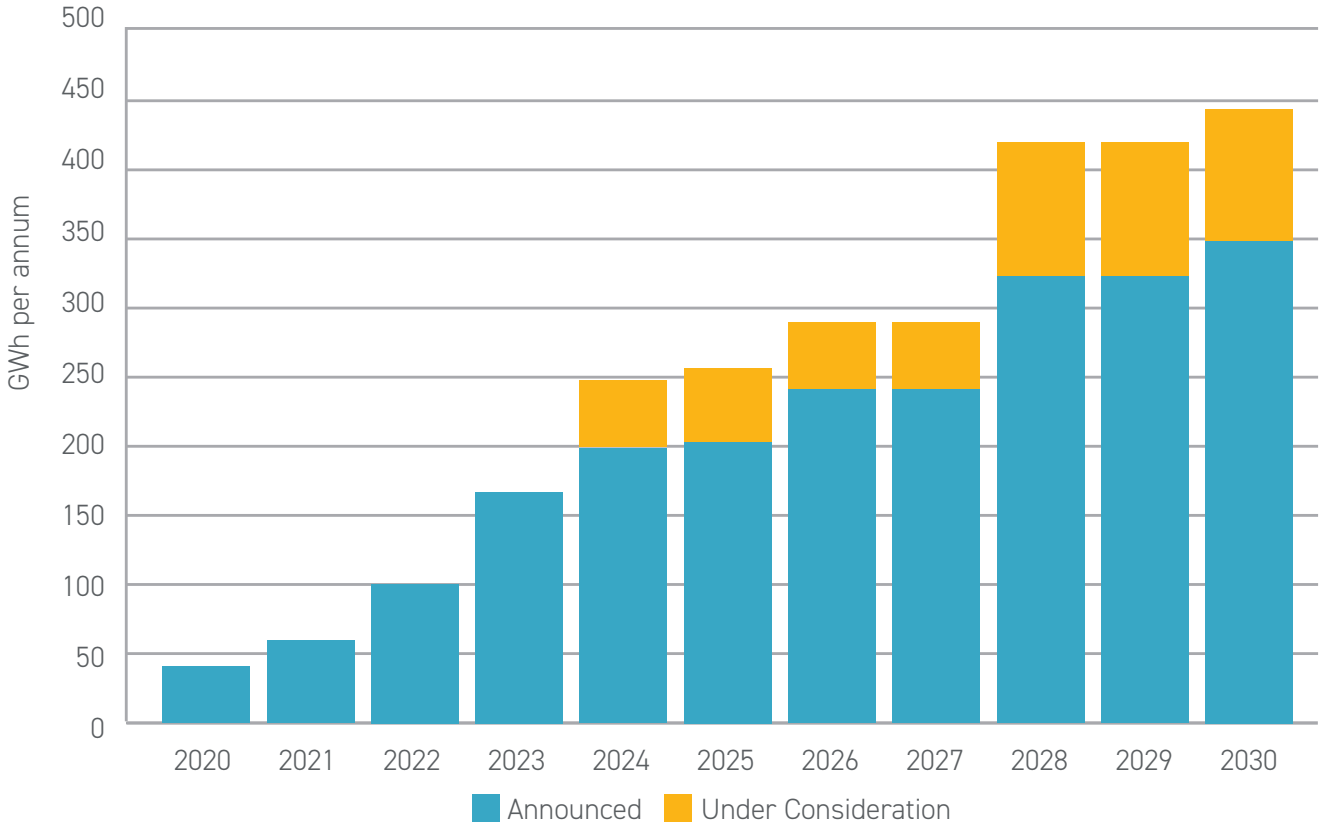
SK Innovation, Komárom (Hungary). Two plants announced with a combined annual capacity of 20 GWh.

Saft, (France and Germany). A Saft and PSA Group joint venture announced 2 plants of 24 GWh per annum each by 2030.

Source: Faraday Institution research, EBRD, Benchmark Minerals Intelligence, Reuters, various sources.

Based on current plans alone, total battery manufacturing capacity in the major centres in continental Europe will reach nearly 450 GWh per year by 2030. Germany is the leading location of choice accounting for 38% of capacity in 2030, followed by Poland (16%) and Sweden (13%). The Nissan Sunderland battery manufacturing plant currently has a capacity of 2 GWh and is estimated to increase to 6 GWh by 2030 (just 1.3%).[19]

European lithium-ion gigafactory battery manufacturing capacity to 2030



[19] Benchmark Minerals Intelligence (January 2020). Lithium Ion Battery Megafactory Assessment.

Without urgent action from stakeholders, the UK is in danger of losing out in the race to develop a large scale domestic EV battery supply through the required investment in new factories. Our modelling shows that, in order to realise a successful EV transition through a ramp-up of UK battery manufacturing capacity by 2040, investment in the range of £12 billion will be required. This level of investment in UK battery production is currently being put at risk, as domestic vehicle manufacturers are already negotiating long-term contracts with battery suppliers outside the UK.

Over the past 2 years, a flurry of deals between EV battery manufacturers and vehicle producers have been announced. Focussing on European car producers, for example:

• LG Chem has announced relationships with Volkswagen[20] , PSA[21] and Renault;[22]

• CATL has announced a relationship with BMW;[23] and

• Northvolt and Volkswagen Group have formed a joint venture[24] and European Battery Union.[25]

In the UK, there are only a handful of volume producers (factories producing more than 100,000 units per year). These are Nissan, Jaguar Land Rover (JLR), BMW Mini, PSA's Vauxhall and Toyota. There is no reason to suppose that these firms will naturally gravitate towards establishing all, or even any serious proportion, of their European battery manufacturing capacity in the UK. If, on the contrary, they enter long-term relationships with overseas battery suppliers, then the chances of securing UK gigafactories (and hence the chances of sustaining an EV production industry in the UK) will diminish.

The UK Government has already made a great start through the investment in the Faraday Battery Challenge. It has also identified EV and EV battery manufacturing as a strategic priority going forward. A further £1 billion (the Automotive Transformation Fund) has been identified to "develop and embed the next generation of cutting-edge automotive technologies"[26] and plans for a gigafactory were set out in the Conservative Party Manifesto 2019.

Alongside this support and commitment, the UK Government could increase the probability of securing UK gigafactories even further by helping to facilitate the winning of new volume EV model lines to UK-based plants. For instance, should half of the production of a single volume model of a larger vehicle produced in the UK be fully electrified, this would generate nearly enough demand for one additional gigafactory in the UK.

Various promising initiatives have already been announced by UK vehicle manufacturers. Jaguar Land Rover already has a portfolio of fully electric, plug-in hybrids and mild hybrids EVs and has stated that every Jaguar and Land Rover launched from 2020 will be electrified,[27] such as the all-electric next generation XJ planned to be manufactured at Castle Bromwich. JLR also expects that their planned battery pack assembly centre at Hams Hall near Birmingham will be operational in 2020.[28] Manufacture of a fully electrified Mini has also started at the BMW Mini plant in Oxford and will be available in showrooms from March 2020.[29]

[20] Reuters (4 October 2018). LG Chem to supply EV batteries to Volkswagen from late 2019.
[21] Reuters (7 March 2017). PSA chooses LG and China's CATL for batteries in future hybrid car.
[22] Reuters (30 September 2010). South Korea's LG Chem to supply batteries to Renault.
[23] Reuters (30 September 2010). China's CATL to build its first European EV battery factory in Germany.
[24] Volkswagen Group News (9 June 2019). Volkswagen and Northvolt form joint venture for battery production.
[25] Green Car Congress (21 March 2019). Volkswagen Group forms European Battery Union with Northvolt.
[26] Government Press Release (8 October 2019). New measures to back business, boost innovation and supercharge UK science.
[27] JLR news (19 March 2019). Jaguar Land Rover installs UK's largest smart charging facility.
[28] JLR news (5 July 2019). Jaguar Land Rover accelerates electrification.
[29] https://www.mini.co.uk/en_GB/home/range/mini-electric.html

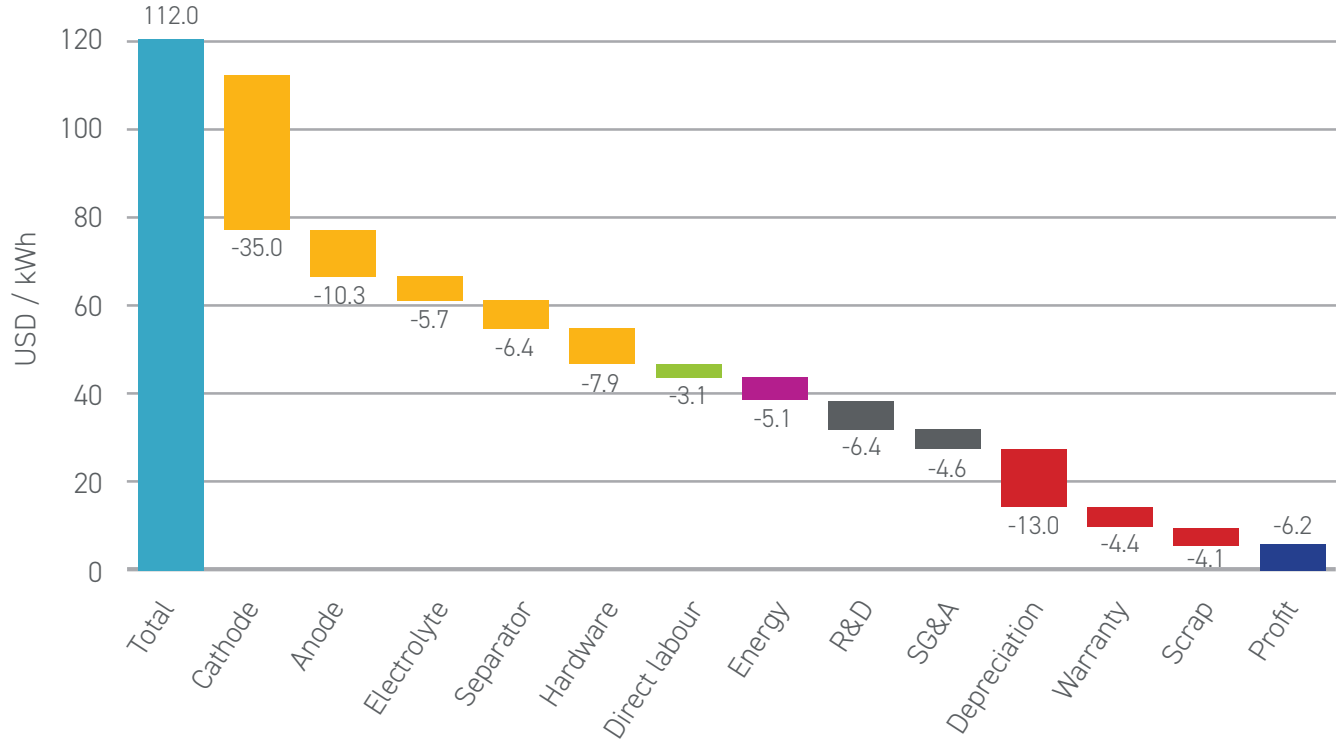
Factors influencing gigafactory investment decisions

But this is a case of two-way causality. Just as the investments in UK gigafactory battery production will depend upon the presence in the UK of major EV production lines, so the presence of EV production lines will depend upon the willingness of the battery manufacturers to invest in the UK. Therefore, UK industry and government stakeholders need to consider carefully how to secure gigafactory investments. As a battery plant generally takes five to seven years to reach full operational capacity, a decision about the siting of a gigafactory would need to be made in 2020 in order to meet the EV battery demands of the mid-2020s.

We asked leading battery firm executives to list the factors that have most impact on their decisions to locate in one country rather than another. Proximity to customers (i.e. EV manufacturers) emerged as the most important factor; hence, if the UK can build upon its existing vehicle manufacturing base, it can hope to attract the battery manufacturers and therefore sustain significant EV production. But the battery manufacturers also told us that they were influenced by investment incentives, timely permitting and licensing arrangements, cheap and clean energy and a skilled and productive workforce. We need to recognise that the UK is in a global, country versus country, competition, and that others are forming persuasive propositions.

These responses were not surprising. In our analysis of the cost components of lithium-ion battery cells, the majority of costs are not production-location specific. Most notably, raw materials make up over half of the cost of a lithium-ion battery cell. Only three components of the cost of batteries are location specific, namely direct labour, energy and utilities, and depreciation. None of these (other than energy infrastructure costs) can easily be affected by specific government actions; and, combined, they account for around 20% of overall costs.

Average cost structure of Li-ion cell in 2019



Source: Estimates from Faraday Institution, Element Energy, BNEF,[30] various sources.

[30] CleanTechnica (4th December 2019). Powering the EV Revolution.

The UK accordingly cannot hope to attract gigafactories through the provision of an intrinsically low cost-base and therefore needs to match or come closer to matching the financial and administrative incentives that have been offered by other European countries to EV battery manufacturing firms. We conclude that HM Government, working with relevant Local Enterprise Partnerships (LEPs) and Combined Authorities, should consider the following actions:

1. further moves to establish coordinated, ambitious and centralised leadership on this issue;[31]

2. further efforts to communicate the attractiveness of the UK as a global and regional battery manufacturing location; drawing on the content of this report; and

3. new efforts to de-risk the business case by undertaking prospective site selection, the preapproval of relevant permissions, the construction of basic on-site physical (especially energy) infrastructure and the development of the requisite EV battery skills and training infrastructure.

In addition, details are required for the £1 billion pledged by Government in October 2019 to "develop and embed the next generation of cutting-edge automotive technologies."

Overall, the UK has had a head start with the establishment of the largest European battery factory in Sunderland in 2010, yet we risk falling behind in the race to secure the next generation of battery factories. Within a year, most car producers and battery manufacturers will make their decisions about where in Europe the next generation of gigafactories will be built. We need a timely and coordinated effort by government and industry leaders to attract these gigafactories to the UK, and to secure the future for our automotive industry.

Acknowledgments

This report is an update by the Faraday Institution of a study with the same scope that it produced in 2019 in consultation with experts from McKinsey Energy Insights and individuals from the University of Oxford.

[31] As suggested by OEMs interviewed for this study.

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